BRITISH ENCODER PRODUCTS COMPANY

WHITE PAPER

# Industrial Ethernet Communication Protocols

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## Executive Summary

Industrial communications like all technologies, have undergone significant changes. Industry was once dominated by serial networks that utilized the technology that served the contemporary needs of the marketplace. Higher speeds and greater throughput are now needed to facilitate new, more sophisticated slave devices, end-node equipment, together with new applications. As a result, industrial communications equipment has been transitioning to faster, deterministic Ethernet-based technology and communications protocols, yet no specific communications protocol has come to dominate the industry. In today's market slave communications are supported by a multiplicity of communications protocols, each providing its own set of capabilities and advantages.

## Industrial Slave Equipment

Here, we will look at some past serial based protocols together with industrial Ethernet protocols and learn how they fit into the industrial automation world, illustrated in Figure 1, to deliver real-time, determinism, and the low latency required for industrial communications.

Industrial slave equipment presents a host of challenges for manufacturers. Industrial slave equipment includes: programmable logic controllers (PLCs), industrial drives, sensors connected to fieldbuses, human/machine interface systems, grid infrastructure communications, industrial gateways, and other types of systems. Most equipment has been built around hardware-based protocol execution. Equipment manufacturers have had to support different hardware configurations of their products, each tuned to a specific protocol. This situation is triggering a transition for industrial slave communications, toward programmable software-based protocol execution, which enables multi-protocol industrial slave communication systems. Greater programmability is ushering in greater flexibility and agility for manufacturers, enabling them to offer cost-effective configurable solutions to their users who are deploying industrial networks, with a decrease in Total Cost of Ownership (TCO).

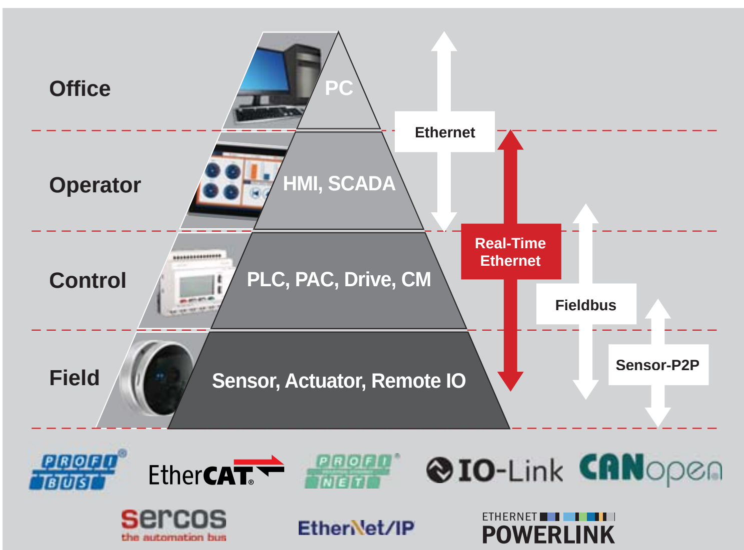


*Figure 1: Industrial Automation Pyramid*

## Industrial Automation Components

Communication is the backbone of all industrial automation components for efficient production systems. There are four major components in industrial automation including PLC controllers, HMI panels, industrial drives, and sensors. Figure 2 illustrates these primary industrial automation components showing how all work together.

The PLC controller is the nexus of an industrial automation system; it provides relay control, motion control, industrial input and output process control, distributed system, and net-working control for the system.

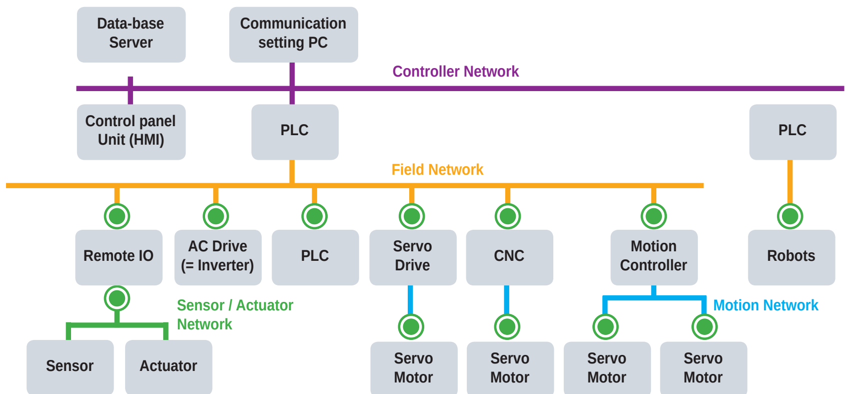


*Figure 2: Industrial Automation Network*

The HMI is the graphical user interface for industrial control. It provides a command input and feedback output interface for controlling industrial machinery. An HMI is connected through common communication links to other parts of industrial systems.

Industrial drives are motor controllers used for controlling optimal motor operation. They are used in a very diverse range of industrial applications, and come with a wide range of voltage and power levels. Industrial drives include but are not limited to AC and DC drives as well as servo drives that use a motor feedback system to control and adjust the behavior and performance of servo mechanisms.

Sensors provide direct measurement for industrial automation systems that monitor the industrial operating conditions, inspections, position measurements, and much more, in real time. They are an integral part of industrial automation systems and provide trigger points and feedback for system control.

## Legacy Industrial Communication Protocols

First generation industrial communications networks were built on a variety of serial-based interfaces originally created by different companies that later became de-facto standards. The result being many different standards in the marketplace. Large companies were behind these de-facto standards pushing them in the marketplace. Industrial automation equipment companies were then compelled to implement many of these protocols. Many serial-based protocols, including PROFIBUS, CAN bus, Modbus, CC-Link, and standard RS-422/RS-485 remain popular today due to the long life cycles of industrial systems.

These interfaces, many of which are still in use today, were slow and limited by the number of addresses (or number of slave nodes supported) on any one network segment. Throughput rates ranged upward to 12 megabits per second (Mbps) and a network could typically support no more than several hundred addresses for end nodes. These networks made e ective use of the technology of the day and have stood the test of time. While the number of slave nodes supported is still considered sufficient, when combined with slow bus speeds, the time to exchange data between master and slave increases. This is especially critical as end nodes get more sophisticated with higher sensor integration, added intelligence, greater spatial separation, and eventually more data.

**PROFIBUS**

PROFIBUS is widely deployed in industrial automation systems including those for factory and process automation. PROFIBUS provides digital communication for process data and auxiliary data with speeds up to 12 Mbps supporting up to 126 addresses.

**CAN-**

Control Area Network (CAN) bus, is a high-integrity serial bus system. It was originally created as an automotive vehicle bus and later came to be used as one of the fieldbuses for industrial automation. It provides a physical and data link layer for serial communication with speeds up to 1 Mbps. CANopen and DeviceNet are higher level protocols standardized on top of CAN bus to allow interoperability with devices on the same industrial network. CANopen supports 127 nodes on the network while DeviceNet supports 64 nodes on the same network.

**Modbus**

Modbus is a simple, robust and openly published, royalty free serial bus that connects up to 247 nodes together in the link. Modbus is easy to implement and runs on RS-232 or RS-485 with physical links speeds up to 115K baud.

**CC-Link**

CC-Link was originally developed by the Mitsubishi Electric Corporation in 1997 and is a popular open-architecture, industrial network protocol in Japan and Asia. CC-Link is based on RS-485 and can connect with up to 64 nodes on the same network with speeds up to 10 Mbps.

## Descriptions of Industrial Ethernet Communication Protocols

Ethernet is cost effective and ubiquitous, offering common physical links with increased speed. As a result, many industrial communication systems are moving to Ethernet based solutions as illustrated in Figure 3. As the applications running on industrial networks became more sophisticated, they required greater and faster data transfer speeds. Ethernet based networking technology has provided a solution, as it is very cost effective, widely deployed, and understood. It is capable of much higher bandwidth performance than the serial fieldbus interfaces and scalable practically to an unlimited number of nodes. These capabilities translate into improved manufacturing yields, the ability to deploy new, more demanding applications and improved TCO.

However, before industrial Ethernet could be widely deployed, its primary constraint had to be overcome. Since the original Ethernet protocol relied on Collision Sense Multiple Access with Collision Detection (CSMA/CD) mechanisms, it could not provide the determinism or predictability required by real-time communications applications such as industrial network-ing. Modifications could fortunately be made to Ethernet's Media Access Control (MAC) layer to facilitate real-time predictability and low latency response times. Now, several of the more popular real-time industrial Ethernet protocols will support networking speeds in the 100 megabits per second (Mbps) and the gigabit per second (Gbps) range going forward. The most prominent real-time Ethernet protocols today include EtherCAT, EtherNet/IP, PROFINET, POWERLINK, Sercos III, Modbus TCP, and CC-Link IE. Ethernet also en-ables exible network topologies that scale with the number of network nodes.-

# Industrial Ethernet Communication Protocols

Ethernet communications using standard TCP/UDP/IP are nondeterministic, with typical cycle times greater than 1000 ms, and packets subject to collision on the wire. Some Industrial Ethernet protocols use a modified Media Access Control (MAC) layer to achieve low latency and deterministic responses.

Table 1 illustrates the umbrella organizations responsible for each Industrial Ethernet type discussed here.

Figure 5 on the following page illustrates how the Industrial Ethernet protocols relate to standard TCP/UDP/IP based Ethernet, together with their MAC layer modifications. Ethernet/IP, Modbus, and standard PROFINET protocols are completely TCP/UDP/IP based. Standard Ethernet switches and controllers can be used in the network (Figure 5a). For PROFINET RT and POWERLINK, process data is carried over TCP/UDP/IP with timing controlled by a process data driver. Standard Ethernet switches, hubs, and controllers can be used in the network (Figure 5b). For PROFINET IRT, CC-Link IE, SERCOS, and EtherCAT, process data is carried over TCP/UDP/IP with timing controlled by a process data driver. Special Ethernet link layer/MAC hardware is required for protocol slave devices to realize determinism (Figure 5c).

Nearly all Industrial Ethernet protocols, if not entirely TCP/UDP/IP based, provide some mechanism to encapsulate and carry standard Ethernet frames, (for example Ethernet-Over EtherCAT - EOE).

When using an Ethernet packet sniffer such as Wireshark, most Industrial Ethernet frames are identified by checking the ETHERTYPE ID eld. Table 2 illustrates how each of the different Industrial Ethernet types are detected using the Ethernet frame ETHERTYPE ID.

## Ethernet/IP

EtherNet/IP is an industrial Ethernet protocol originally developed by Rockwell Automation that is now managed by the Open DeviceNet Vendors Association (ODVA). Unlike EtherCAT, which is a MAC-layer protocol, EtherNet/IP is an application-layer protocol built on top of TCP/IP. EtherNet/IP uses standard Ethernet physical,

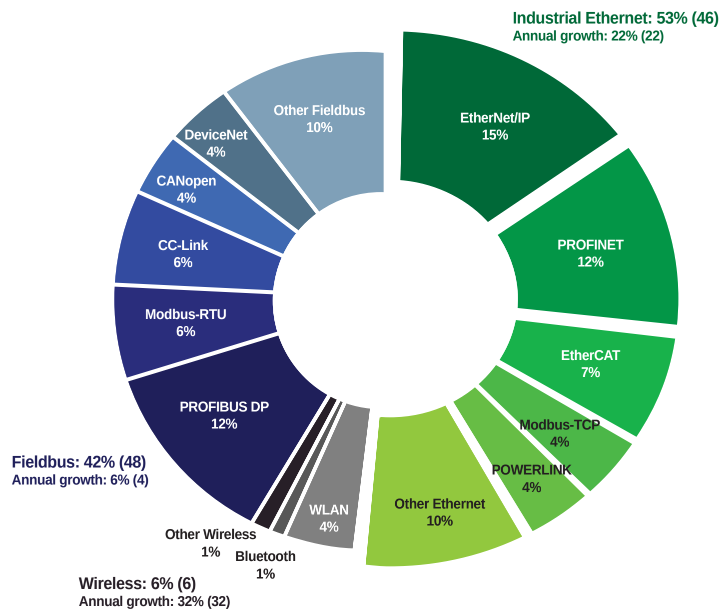


*Figure 3: Industrial Ethernet Market Share 2017: Source: HMS*

| Industrial Ethernet Protocol | Organization | Contact |
|---|---|---|
| PROFINET | PNO | www.pro bus.com |
| POWERLINK | ESPG | www.ethernet-powerlink.org |
| Ethernet/IP | ODVA | www.odva.org |
| EtherCAT | ETG | www.ethercat.org |
| SERCOS III | SERCOS International | www.sercos.org |
| MODBUS TCP | Modbus Organization | www.modbus.org |
| CC-Link IE | CLPA | www.cc-link.org |

*Table 1: Industrial Ethernet organizations*

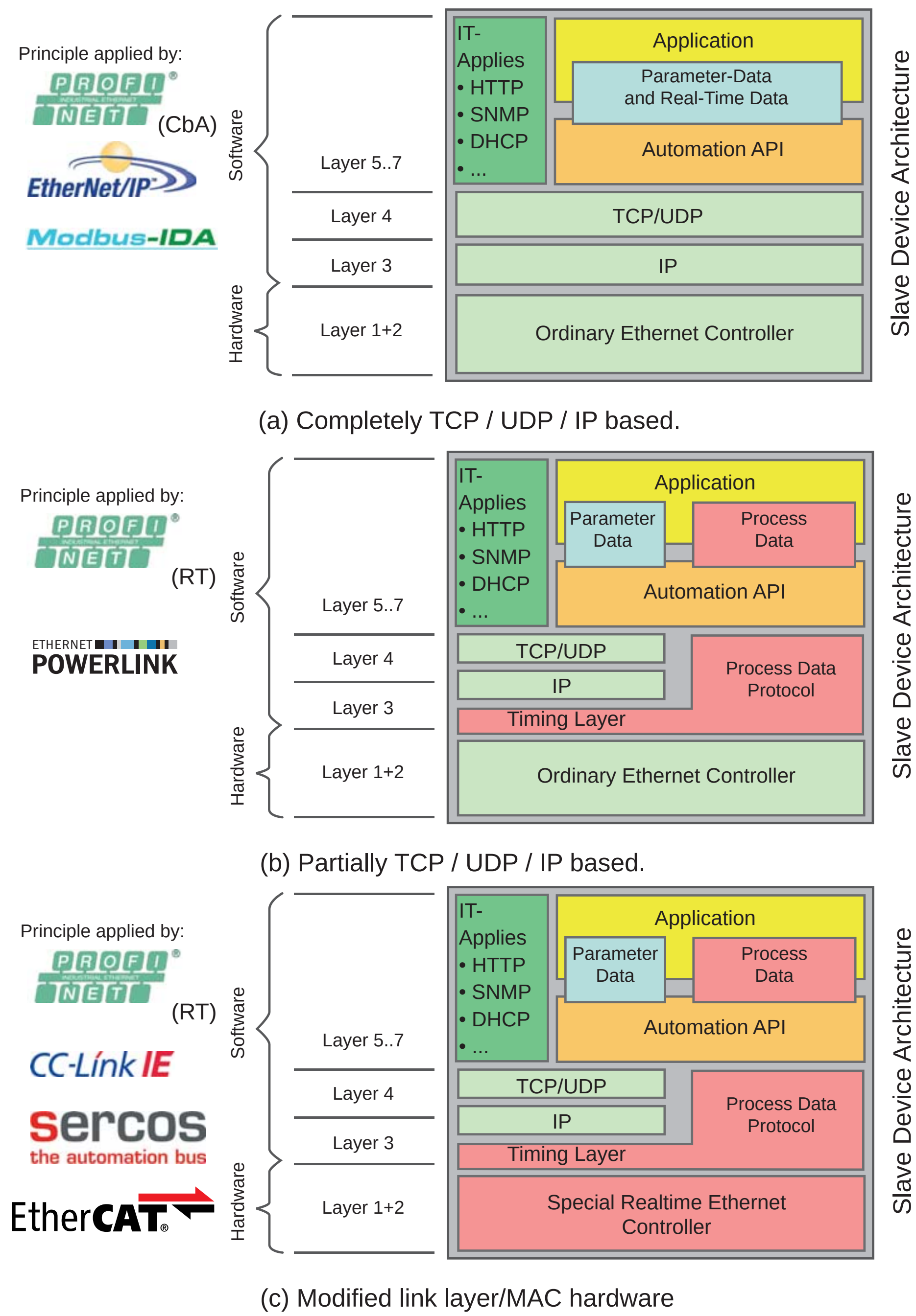


*Figure 5: Basis for Industrial Ethernet protocols. Source: ETG*

# Industrial Ethernet Communication Protocols

data link, network and transport layers, while using the Common Industrial Protocol (CIP) on top of TCP/IP. CIP provides a common set of messages and services for industrial automation control systems, where it can be used with multiple physical layer media. For example, CIP over CAN bus is called DeviceNet, CIP over a dedicated network is called ControlNet, and CIP over Ethernet is called EtherNet/IP. EtherNet/IP establishes communication from one application node to another through CIP connections over a TCP connection; multiple CIP connections can be established over one TCP connection.

EtherNet/IP uses standard Ethernet with switches, thus it can have an unlimited number of nodes in a system. This enables one network across many different end points in a factory floor. Ethernet/IP offers complete producer-consumer service and enables very efficient slave peer-to-peer communications. EtherNet/IP is compatible with many standard Internet and Ethernet protocols, but has limited real-time and deterministic capabilities without careful network planning.

**PROFINET**

PROFINET is widely used by major industrial equipment manufacturers such as Siemens and GE. It has three different classes: (1) PROFINET Class A provides access to a PROFIBUS network through proxy, bridging Ethernet and PROFIBUS with a remote procedure calling on TCP/IP. Its cycle time is approximately 100 ms, and is primarily used for parameter data and cyclic I/O. The typical application includes infrastructure and building automation. (2) PROFINET Class B, also referred as PROFINET Real-Time (PROFINET RT), introduces a software-based real-time approach and has reduced the cycle time to approximately 10 ms. Class B is typically used in factory automation and process automation. (3) PROFINET Class C (PROFINET IRT), is Isochronous and real-time, requiring special hardware to reduce the cycle time to less than 1ms to deliver sufficient performance on the real-time industrial Ethernet for motion control operations.

PROFINET RT can be used in PLC-type applications, while PROFINET IRT is a good fit for motion applications. Branch and Star are the common topology used for PROFINET. Careful topology planning is required for PROFINET networks to achieve the required performance of the system.

**EtherCAT**

EtherCAT was originally developed by Beckhoff to enable on-the-fly MAC packet processing and deliver real-time Ethernet to automation applications. It can provide scalable connectivity for entire automation systems, from large PLCs all the way down to the I/O and sensor level.

EtherCAT is a protocol optimized for process data, using standard IEEE 802.3 Ethernet Frames. Each slave node processes its datagram and inserts the new data into the frame while each frame is passing through. The process is handled in hardware (at the MAC layer) so each node introduces minimum processing latency, enabling the fastest possible response time. EtherCAT is a MAC layer protocol and is transparent to any higher level Ethernet protocols such as TCP/IP, UDP, Web server, etc. It can connect up to 65,535 nodes in a system The EtherCAT master can be a standard Ethernet controller, thus simplifying the network configuration. Due to the low latency of each slave node, EtherCAT delivers flexible, low-cost and network-compatible industrial Ethernet solutions.

**SERCOS III**

Sercos III is the third generation of Serial Real-time Communication System (Sercos). It combines on-the-fly packet processing for delivering real-time Ethernet with standard TCP/IP communication to deliver low latency industrial Ethernet. Much like EtherCAT, a Sercos III slave processes the packet by extracting and inserting data to the Ethernet frame on-the-fly to achieve low latency. Sercos III separates input and output data into two frames. With cycle times from 31.25 microseconds, the speed rivals that of EtherCAT and PROFINET IRT. Sercos supports ring or line topology. Sercos III is limited to 511 slave nodes in one network and is most used in servo drive controls.

**CC-Link IE**

CC-Link IE is the industrial Ethernet technology of CC-Link, which was originally developed by the Mitsubishi Electric Corporation. CC-Link IE has two versions: CC-Link IE Control and CC-Link IE Field. CC-Link IE Control is intended for controller-to-controller communications and is limited to 120 nodes per network. CC-Link IE Field is intended for I/O communications and motion control, and is limited to 254 nodes per network. CC-Link IE leverages the Ethernet data link layer, and its control frames are directly embedded in the Ethernet frame. Only ring topology is supported in CC-Link, without switches. This can provide network redundancy, but only a limited number of nodes can be supported in a network, and the cycle time is dependent on the number of the nodes in the network.

**Powerlink**

POWERLINK was originally developed by B&R. Ethernet POWERLINK is implemented on top of IEEE 802.3 and, therefore, allows a free selection of network topology, cross connect and hot plug. It uses a polling and time slicing mechanism for real-time data exchange. A POWERLINK master or Managed Node controls the time synchronization through packet jitter in the range of tens of nanoseconds. Such a system is suitable for all kinds of automation systems ranging from PLC-to-PLC communication and visualization down to motion and I/O control. Barriers to implement POWERLINK are quite low due to the availability of open-source stack software. In addition, CANopen is part of the standard which allows for easy system upgrades from previous fieldbus protocols.

**Modbus /TCP**

Modbus /TCP is an extension of serial Modbus®, and was originally developed by Schneider Electric. It uses serial Modbus messaging over TCP/IP on top of Ethernet. Modbus/TCP is simple to implement on the standard Ethernet network, but it does not guarantee real-time and deterministic communications: it is a non real-time approach to networking within the industrial environment. It does not guarantee arrive times or cycle times nor provide precise synchronization. Performance is a strong function of the underlying TCP/UDP/IP stack implementation.

# Industrial Ethernet Communication Protocols

## Future Trends

As the third industrial revolution dawns industrial automation will again drive the world economy. The success of industrial automation depends on a reliable and efficient communication network that connects all components of the factory seamlessly working together. The popularity and ubiquity of Ethernet will continue to motivate the legacy factory to upgrade to Industrial Ethernet. Many different Industrial Ethernet protocols have been implemented in the field, each with its strengths and weaknesses. Future Industrial Ethernet protocols will continue to evolve and converge to deliver hard real-time, deterministic communication links with better reliability and integrated safety. For more information on the BEPC absolute Ethernet product line, please visit BEPCs Encoders for Industrial Ethernet overview page.

  